Birth Weight and Exposure to Kitchen Wood Smoke During Pregnancy in Rural Guatemala

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In this study, we aimed to establish whether domestic use of wood fuel is associated with reduced birth weight, independent of key maternal, social, and economic confounding factors. We studied 1,717 women and newborn children in rural and urban communities in rural Guatemala. We identified subjects through home births reported by traditional birth attendants in six rural districts (n = 572) and all public hospital births in Quetzaltenango city during the study period (n = 1,145). All were seen within 72 hr of delivery, and data were collected on the type of household fuel used, fire type, and socioeconomic and other confounding factors. Smoking among women in the study community was negligible. Children born to mothers habitually cooking on open fires (n = 861) had the lowest mean birth weight of 2,819 g [95% confidence interval (CI), 2,790–2,848]; those using a chimney stove (n = 490) had an intermediate mean of 2,863 g (95% CI, 2,824–2,902); and those using the cleanest fuels (electricity or gas, n = 365) had the highest mean of 2,948 g (95% CI, 2,898–2,998) (p < 0.0001). The percentage of low birth weights (< 500 g) in these three groups was 19.9% (open fire), 16.8% (chimney stove), and 16.0% (electricity/gas), (trend p = 0.08). Confounding factors were strongly associated with fuel type, but after adjustment wood users still had a birth weight 63 g lower (p = 0.05; 95% CI, 0.4–126). This is the first report of an association between biofuel use and reduced birth weight in a human population. Although there is potential for residual confounding despite adjustment, the better-documented evidence on passive smoking and a feasible mechanism through carbon monoxide exposure suggest this association may be real. Because two-thirds of households in developing countries still rely on biofuels and women of childbearing age perform most cooking tasks, the attributable risk arising from this association, if confirmed, could be substantial. ***Key words*****: biofuel, carbon monoxide, indoor air pollution, low birth weight.** ***Environ Health Perspect*** **110:109–114 (2002). [Online 19 December 2001]**
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Low birth weight (LBW), defined as birth weight < 2,500 g, is well established as an important risk factor for infant mortality and morbidity. Well over 90% of all LBW babies are born in developing countries, where approximately 18% of newborns weigh less than 2,500 g[2]. In Guatemala, for the period 1990–1994, 14% of all births fell into this category (*1*), although there are substantial variations within the country (*2*). LBW results from a wide range of factors that determine premature birth, intrauterine growth retardation, or combinations of both of these outcomes (*3*). Any conditions that interfere with transplacental delivery of nutrients, oxygen included, may cause varying degrees and types of intrauterine growth retardation (IUGR). Of the environmental factors linked with reduced birth weight, tobacco smoking—both active and passive—has probably been the most extensively studied (*4–8*). Active smoking is associated with a mean reduction in birth weight of up to 200 g, whereas passive smoking has a smaller effect variously estimated at 20–120 g (*9–12*). A recent meta-analysis reported a weighted estimate of 28 g, with a greater decrement of 40 g when pooling was restricted to the more homogeneous studies (*8*).

Tobacco Smoke, Biofuels, and Low Birth Weight

Although over 4,000 substances have been identified in cigarette smoke, only a few dozen are singled out as important from a health perspective. Carbon monoxide (CO) in particular and possibly nicotine are regarded as the agents most likely to be responsible for detrimental effects on intrauterine growth (*10,13,14*). CO results from the incomplete combustion of any biomass, which includes tobacco and biofuels (wood, dung, and fiber residues) as well as fossil fuels such as coal and gas, which are used for cooking and heating (*15*). Once inhaled, CO combines with hemoglobin to form carboxyhemoglobin (COHb), a much more stable compound that does not readily give up O_2 to peripheral tissues and organs, including the fetus.

In terms of emissions of suspended particulates and pollutant gases, the combustion of wood and other biomass is qualitatively similar to the burning of tobacco, although without the nicotine. Studies have shown that exposure to biofuels is associated with COHb levels of 2.5–13% (*16,17*), covering the range seen for passive through heavy active smoking (*18,19*). It is therefore not unreasonable to expect that the effect of passive smoking on birth weight would also apply to pregnant women habitually exposed to high levels of biofuel smoke, as is the case in developing countries (*20,21*). However, despite the theoretical similarity between passive tobacco smoking and prolonged indoor exposure to high levels of wood smoke, we are not aware of any previous published studies that have examined the effects of the latter on human fetal growth.

Around two-thirds of households in developing countries still rely on biofuels as their primary fuel (*22*), and unless there is a major change in energy and development policy in developing countries, such use will continue for the forseeable future (*23*). It is now recognized that indoor use of biofuel in rural communities is responsible not only for some of the highest levels of ambient air pollution ever recorded (*15*) but also for about half the global burden of exposure to airborne pollutants (*24*). It is therefore essential to examine the effect of indoor smoke exposure and LBW in developing countries. Our study had the following objectives: to quantify the influence of biofuels use on birth weight, and to measure and control for potential confounding factors such as maternal education, health and nutritional status, and socioeconomic conditions.

Methods

Background information on study area. The study was performed in Quetzaltenango, a mountainous province in western Guatemala, where the prevalence of LBW was estimated at 18% in 1988 (*24*). In the National Micronutients Survey, performed by the Ministry of Public Health in 1995 (*25*), the prevalence of anaemia (Hb < 11 g/dL) corrected for altitude and pregnancy among women ages 15–48 years in the western highlands was 39%, the highest regional value for the country. Malaria is not endemic in the study districts because of the high altitude (2,300–2,700 m). At least 70%

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of all deliveries occur at home, and 95% of these with the assistance of traditional birth attendants.

The study was performed in 6 of the 22 districts of Quetzaltenango province as well as the provincial capital. Women and their babies were recruited from home births (n = 572) and hospital births (n = 1,145).

Home deliveries. During 6 consecutive months (October–March), data were collected prenatally on 572 pregnant women in their second or third trimester by seven trained female field workers living within the six districts (San Juan, Almolonga, Olintepeque, Concepción, Sibilia, and Sija). All district townships were within a 20-km radius of the provincial capital. Pregnant women were either referred to the field workers by volunteer traditional birth attendants or directly identified by the field workers at the larger villages within each district. Subjects were included if the newborn was alive by the time of the first visit (within 72 hr after delivery). The smaller, more remote communities were excluded to ensure that field workers were available to identify and examine as many neonates as possible within 72 hr.

Hospital deliveries. All consecutive hospital births occurring in the public regional hospital in Quetzaltenango City during the same period as for recruitment of home births were included in the study (n = 1,145). Subjects were examined by a trained professional nurse stationed in the hospital as soon as routine hospital neonatal procedures permitted and always within the first 24 hr after delivery. Of these, 188 babies were born to women residing within the six districts covered by the project field workers assessing home deliveries. The remaining 950 hospital deliveries occurred in other districts of the province.

To help ensure that home-delivered neonates were seen within 3 days after birth, field workers had to reside in their district township. We excluded stillbirths (2), multiple births (3), children with gross anatomic deformities (2), and other children who died before being measured (12 of the home deliveries; 0 hospital deliveries).

Field workers were trained by E. Boy in all interview and examination procedures. The interview included questions on the type of fuel used for cooking (wood, coal, electricity, gas) and (if wood or coal) whether this was burned on an open fire or in a stove with a chimney. We included women reporting that they smoked cigarettes and recorded the number of cigarettes consumed per day. We assessed socioeconomic status through questions on house construction, particularly the floor material, and also through questions on literacy and marital status. Questionnaires were checked, and if necessary a repeat visit was made by the field supervisor to rectify errors.

We calculated gestational age using the date of the last menstrual period and compared it to the gestational age estimated postnatally by grading the somatic characteristics of the newborn babies, which were registered on a pictorial format (*26*). Birth weight was measured to the nearest 50 g (home deliveries) or 25 g (hospital deliveries). The neonates were weighed naked and indoors in a warm environment. When a mother declined to completely undress her baby (8% of cases, all from Almolonga), a shirt and cap of sizes similar to those worn by the baby were weighed, and this weight was subtracted from the total weight recorded for the dressed baby. The time between birth and the weighing of the child was also recorded. Maternal anthropometric measurements were read to the nearest 0.1 cm, following standard procedures (*27*). For height, a stationary stadiometer was used at the hospital. For home deliveries a nonextensible measuring tape (180 cm) set on a straight wall (verified with a plumb line perpendicular to level ground) was used. Maternal calf circumference was measured on the right leg with the woman standing, by sliding the measuring tape around the naked calf until the maximum perimeter was identified at the same point on at least 3 consecutive occasions. The portable Salter spring scales (50 g intervals) and stadiometers used for neonates were calibrated monthly.

We analyzed the association between fuel type and birth weight with adjustment for confounding using linear regression with the GLM procedure of the SAS Institute statistical software (SAS/STAT version 6.0; SAS Institute, Cary, NC, USA).

Results

We studied 1,717 mothers and children. Table 1 shows the number of children of normal and low birth weight (< 2,500 g) for the hospital and home births in the city, each of the six named districts, and the group of all other districts. The overall percentages of LBW were 18.8% for the hospital birth group and 17.1% for the home birth group. This difference is nonsignificant (p = 0.4055) even when the city residents are excluded from the analysis (p = 0.2512). The sample included all hospital births that occurred during the study period, but probably only about 30% of home births from the six districts where these were recruited. For two districts (Sibilia, Sija), all birth certificates were counted: 30% and 25% of these births, respectively, had been effectively included in the study. Because about 30% would have taken place in hospital, the study included around 40–50% of all home births. This relatively low percentage derives from the restriction of recruitment to the larger rural communities. The implications of this are considered further in Table 1.

Only 14 (0.82%) of the women reported smoking during pregnancy. Of the 313 women with LBW babies, four (1.28%) smoked during pregnancy. Of the 1,404 normal weight births, 10 (0.71%) smoked. This difference was not significant (p = 0.3). The women who reported smoking have been included in the analysis.

Birth weight by type of fuel. Approximately one-half of the women cooked with wood in an open fire, one-third with wood stoves equipped with a chimney, and one-quarter with the cleaner fuels (Table 2). In addition, 14 women, most of whom lived in the city, cooked with coal. In all subsequent analyses, the coal users have been grouped with the wood users according to whether they used coal in an open fire or in a chimney stove. In this univariate analysis of birth weight, the group mean values decrease progressively from 2,948 g for the clean fuels users to 2,863 g for the chimney stove group and 2,819 g for the open fire group. A similar trend is observed for LBW prevalence (Table 2).

The differences between mean birth weight for clean fuels and all wood users

Table 1. Number and percentage of babies by place of birth, birth weight, and district of residence (total n = 1,717).

	Hospital deliveries (n = 1,145)			Home deliveries (n = 572)		
Residence	< 2,500 g (%)	≥ 2,500 g (%)	Total	< 2,500 g (%)	≥ 2,500 g (%)	Total
City	114 (17.9)	522 (82)	636	0 (0)	0 (0)	0
San Juan	8 (21.6)	29 (78.3)	37	29 (29.3)	70 (70.7)	99
Almolonga	3 (60)	2 (40)	5	14 (8.6)	149 (91.4)	163
Olintepeque	10 (17.5)	47 (82.4)	57	3 (9.4)	29 (80.6)	32
Sija	10 (13.8)	62 (86.1)	72	17 (16.8)	84 (83.2)	101
Sibilia	2 (18.2)	9 (81.8)	11	11 (14.7)	64 (85.3)	75
Concepción	2 (33.3)	4 (66.7)	6	24 (23.5)	78 (76.5)	102
Other districts	66 (20.6)	255 (79.4)	321	0 (0)	0 (0)	0
Subtotal	215 (18.8)	930 (81.1)	1,145	98 (17.1)	474 (82.9)	572

combined and between clean fuels and open fire users are highly significant ($p < 0.0001$). Although the percent LBW shows the same pattern, the differences are nonsignificant, even though the chi-square for trend approaches significance ($p = 0.076$).

Other factors associated with low birth weight. Table 3 shows the distribution of a range of key maternal, social, and economic variables, including the type of fuel, for the LBW (< 2,500 g) group and the normal birth weight group. The average age of the neonates at the time of measurement was 15.4 ± 10.6 hr for the hospital deliveries and 41.8 ± 20.3 hr for home deliveries ($t = 35.5$, $p < 0.0001$). However, there was no evidence of an association between the time of the measurement and birth weight. The mean age at measurement was 24.3 ± 19.4 hr for the normal weight neonates and 23.6 ± 17.9 hr for LBW babies ($t = 0.596$, $p = 0.6$), and the Pearson correlation coefficient between age at measurement and birth weight was 0.018 ($p = 0.4$). Not shown in the table are the associations between birth weight and neonatal age and sex. Although 20% of female and 16.5% of male newborns had LBW, female sex was only marginally associated with a higher incidence of LBW (chi-square 3.47, $p = 0.062$). As expected, the incidence of LBW among prematurely born neonates (37%) was higher than among those born ≥ 37 weeks gestation (13.8%) (chi-square 521.9, $p < 0.0001$).

The results in Table 3 show that LBW is significantly associated with younger maternal age, smaller maternal calf circumference, and shorter stature (measures of nutritional status), lesser parity, younger gestational age, maternal illiteracy, marital status, dirt floor (economic status proxy), and the lack of vitamin–mineral supplements during the pregnancy.

Factors associated with type of fuel. Table 4 shows the associations between the type of fuel used and the maternal, social, and economic factors that may confound an association between exposure to biofuel air pollution and birth weight. There are statistically strong associations with all of the factors studied, apart from maternal age, which is more marginal ($p = 0.042$).

Table 2. Mean birth weights and number of births (%) of LBW babies, by type of fuel and stove.

Birth weight statistics	Open fire without chimney	Stove with chimney	Electricity or gas	Total
Number (%)	871 (50.7)	489 (28.5)	357 (20.8)	1717 (100)
Mean birth weight (g)*	2,819	2,863	2,948	2,858
SD (95% CI)	440 (2,790–2,848)	443 (2,824–2,902)	478 (2,898–2,998)	451 (2,837–2,879)
Number (%) LBW** (< 2,500 g)	173 (19.9)	82 (16.8)	57 (16.0)	312 (18.2)

*t-Test: mean birth weight differences: electricity/gas vs. all wood, $p < 0.0001$; electricity/gas vs. open fire, $p < 0.0001$.
**χ^2 Test for percent LBW differences: all categories $p = 0.2$; electricity/gas vs. open fire $p = 0.1$; trend $p = 0.08$.

Table 3. Maternal and household characteristics of LBW babies (< 2,500 g) and normal birth weight babies (≥ 2,500 g).

Subject characteristics	LBW ($n = 313$)	Normal birth weight ($n = 1,404$)	Statistic (p-value)
Continuous variables[a]			
Maternal age	23.7 (6.3)	25.3 (6.1)	3.92 (0.0001
Maternal calf circumference (cm)	29.4 (2.2)	30.7 (2.2)	8.63 (0.0001)
Maternal height (cm)	145.0 (5.9)	146.4 (5.6)	3.70 (0.0002)
Parity	2.1 (2.6)	2.6 (2.6)	2.93 (0.004)
Age when child assessed (hours)	23.6 (18.0)	24.3 (19.4)	0.55 (0.6)
Gestational age	38.2 (1.8)	39.4 (1.2)	12.22 (0.0001)
Categoric variables[b]			
Maternal literacy			
Literate	177 (16.5)	898 (83.5)	6.16 (0.01)
Illiterate	137 (21.2)	508 (78.8)	
Marital status			
Married	168 (15.7)	902 (84.3)	12.86 ($df = 2$)
Cohabiting	120 (22.9)	403 (77.1)	(0.002)
Single	26 (20.6)	100 (79.4)	
Floor material			
Earth	161 (21.1)	601 (78.9)	6.54 (0.01)
Cement or better	150 (16.3)	772 (83.7)	
Place of residence			
Urban	82 (16.5)	414 (83.5)	1.42 (0.2)
Rural	232 (18.9)	990 (81.1)	
Vitamin supplementation			
Yes	175 (15.8)	935 (84.2)	13.0 (< 0.0001)
No	139 (22.8)	471 (77.2)	

df, degrees of freedom.
[a]Mean (SD) within each category of birth weight, using t-test. [b]Number (%) within each category of birth weight, using χ^2.

Most of these findings are to be expected—families in the rural areas rely far more on wood fuel, are poorer and less well nourished, and have lower levels of literacy—but the strength of these associations is notable. The time until examination of the neonate was significantly longer ($p < 0.001$) for the wood-using group because they usually lived farther from the district centers where the field assistants lived. However, this factor should not bias the outcome because these data show no evidence of any association between the time of measurement and birth weight (Table 3).

Multivariate analysis. When fuel type was entered as the three categories presented in Table 2 (clean fuel, chimney stove, open fire), adjusted mean birth weights were 2,834 (gas/electricity), 2,765 (wood/coal stove with chimney), and 2,733 (open fire). The overall difference was nonsignificant, but the difference between the clean fuel group and the chimney stove group was marginally significant ($p = 0.054$). Because this three-level categorization moved fuel type out of the model, and because the difference between the two categories of wood users (chimney stove and open fire) was quite small (32 g), we also performed the analysis using only two categories. Table 5 shows the explanatory variables giving the best fit. The model r-squared is 0.097.

Several important factors remained independently associated with LBW, including fuel type, gestational age < 37 weeks (chi-square 52.9, $p < 0.0001$). Female sex was marginally associated with LBW (chi-square 3.47, $p = 0.06$. The adjusted mean birth weights were 2,772 g for the wood fuel group and 2,835 kg for gas/electricity users, with a mean reduction in birth weight associated with wood use of 63 g ($p = 0.05$; 95% CI, 0.4–126). In general the results are consistent with the findings from the univariate analysis: The strongest associations with birth weight are with calf circumference, parity, floor material, and area of residence. Regarding parity, the only category of previous births significantly different from nulliparity was > 1. Subcategories for non-nulliparous women (0 vs. 1 vs. 2 vs. > 3, for instance) showed no significant association with the risk of LBW. On the other hand, the somewhat surprising finding that urban dwellers had a lower birth weight than rural dwellers is probably explained by the fact that women living in the city who use the public hospital are the least well off among Quetzaltenango residents.

Discussion

In the province of Quetzaltenango, it is estimated that hospital births account for only about 30% of all births, and about 50% of births occurring within the city (*28*).The predominance of hospital-based births in this study means that it is not representative of the whole community, but this method of recruitment was adopted because of the practical difficulties of identifying and examining home births—especially in the smaller and more remote communities. The average value of 18% LBW for the sample is higher than the national UNICEF estimate of 14% (*1*) but in line with what would be expected for this relatively poor province of Guatemala (*2*).

Although the sample may not be representative of the whole community, the most important issue is whether any significant bias has been introduced into the relationship between fuel type and birth weight. This could occur if wood-using families with higher birth weights and/or clean-fuel users with lower birth weights have been disproportionately excluded. We know that wood users are the poorer members of the community, and among hospital births it is the better-off private clinic users (tendency to use clean fuel, lower risk of LBW) that are not included. Among the home births, it is mainly those from the smaller, more remote communities that are not included. These women are likely to be poorer, to use an open fire instead of a chimney stove (and hence be more heavily exposed), and to be at higher risk of having an LBW baby. Therefore, bias from the incomplete sample can be expected to reduce the estimate of any true association between wood fuel and LBW because the rural wood users most at-risk for LBW are those poorer women among whom recruitment was most difficult.

The potential for residual confounding in this study needs to be considered, through limitations of measurement, strong associations between confounders and fuel type, and by omission. However, the other factors independently associated with LBW in this study (Table 5) are consistent with well-established risk factors, and this observation adds weight to the view that these results, though not representative of the whole community, are not seriously biased.

Exposure levels. Another key issue is whether wood fuel users really did have higher exposure to pollutants, particularly to CO, and whether the level of exposure they experienced was sufficient to impair fetal growth. Although exposure was not measured directly in the current study, there is fairly substantial evidence from Guatemala (*16,29–32*) and elsewhere (*15,17,24,33,34*) to answer these questions. Studies from many parts of the world have shown that women are exposed to very high levels of indoor air pollution from biofuels: Typical 24-hr values for particulate matter $(PM)_{10}$ are around 1,000 µg/m^3 or higher (*15,21,24,33*). Ambient 24-hr CO levels are about 5–10 ppm—and 25–50 ppm during use of the fire (*16,31,33*). In this part of Guatemala, Naeher et al. reported time-weighted day time concentrations (breakfast, lunch, and dinner times) of 22.9 ppm (SD + 28.1) for open fire users (*29*).

Studies of COHb levels in people exposed to biofuels have shown levels of 1.5–2.5% (*16*), 3–4% (*34*), up to 13% (*17*). Given the high ambient (room) levels, these findings for COHb are consistent with an ethnographic study in this part of western Guatemala that found that women spend between 4.6–6.8 hr per day in the house while the fire is lit (*32*). The current World Health Organization air quality guidelines recommend exposure to CO of no more than 10 ppm for an 8-hr period and 30 ppm for 1 hr (*18*), levels that are frequently reached or exceeded in homes burning biomass on open fires.

Are these levels sufficient to cause IUGR? Because it is now well established that smoking, including environmental tobacco smoke (ETS) (*8,9,11,12,35*), is associated with LBW, the COHb levels found with active and passive smoking exposure should serve as an adequate indication

Table 4. Distribution of potential confounding factors by type of fuel/stove.

Potential confounding factor	Wood fuel (*n* = 1,360)	Electricity/gas (*n* = 357)	Statistic
Continuous variables: means (SD) within each category of birth weight			*t*-Test (*p*-value)
Maternal age	25.1 (6.4)	24.5 (5.7)	–2.04 (0.04) U
Maternal calf circumference (cm)	30.2 (2.2)	31.2 (2.6)	6.66 (0.0001) U
Maternal height (cm)	145.5 (5.5)	148.6 (5.7)	8.91 (0.0001) E
Parity	2.72 (2.8)	1.80 (1.8)	–7.28 (0.0001) U
Age when child assessed (hr)	26.7 (20.0)	15.0 (10.6)	–14.37 (0.0001) U
Gestational age	39.2 (1.4)	39.4 (1.4)	3.15 (0.002) E
Categoric variables: numbers (%) within each category of birth weight			χ^2 (*p*-value)
Maternal literacy			
Literate	743 (69.2)	330 (30.8)	154.2 (< 0.0001)
Illiterate	609 (94.6)	35 (5.4)	
Marital status			
Married	883 (82.7)	185 (17.3)	7.77 (*df* > 2)
Cohabiting	416 (79.7)	106 (20.3)	(0.02)
Single	92 (73.0)	34 (27.0)	
Floor material			
Earth	720 (94.5)	42 (5.5)	206.9 (< 0.0001)
Cement or better	604 (65.6)	316 (34.4)	
Place of residence			
Urban	230 (46.5)	265 (53.3)	434.5 (< 0.0001)
Rural	232 (18.9)	990 (81.1)	
Vitamin supplementation			
Yes	785 (73.6)	282 (26.4)	88.8 (< 0.0001)
No	549 (92.7)	43 (7.3)	

Abbreviations: *df*, degrees of freedom; E, equal variance; U, unequal variance.

Table 5. Variables in final model giving best fit, with adjusted mean birth weights, effect on birth weight, and significance.

Explanatory variables	Birth weight least-square means (g)	SE (g)	Difference (g) (95% CI)	Student *t* (*p*-value)
Parity				
0	2,751	23.6	105 (50–160)	–3.75
1+	2,856	20.9	(0.0002)	
Mother's age (years)				
14–19	2,764	27.1	79 (18–140)	–2.53
> 19	2,843	18.9	(0.01)	
Fuel type				
Electricity/gas	2,835	28.2	63 (0.4–126)	1.97
Wood	2,772	17.8	(0.049)	
Floor material				
Earth	2,757	23.3	93 (46–140)	–3.89
Cement or better	2,850	18.6	(0.0001)	
Area of residence				
Rural	2,848	20.3	90 (35–145)	3.19
Urban	2,759	24.3	(0.002)	
Vitamins third trimester				
Yes	2,834	21.9	60 (15–105)	–2.62
No	2,774	19.6	(0.009)	
Calf circumference				
< 30.4	2,711	20.3	186 (144–229)	–8.82
> 30.4	2,897	20.6	(0.0001)	

of this. Background COHb levels in nonsmokers are typically 1.2–1.5%, in smokers 3–4%, and reaching ≥ 10% in heavy smokers (*18*). Scherer et al. (*19*) reported COHb levels of 1–3% after 8 hr of ETS exposure, with ambient time-weighted room concentrations of 3,000–4,000 µg/m^3 of respirable suspended particulates and 24 ppm of CO. These values are entirely consistent with those found for biofuel exposure with open fires in Guatemala and many other developing countries.

Animal studies. Astrup et al. (*35*) reported studies of effect of smoking on pregnant women and of breathing increased concentrations of CO on pregnant rabbits. Women who smoke had a mean COHb of 1.92% and mean birth weight 235 g less than those of a nonsmoking group. Rabbits breathing 90 ppm CO produced a COHb of 8–9% and a reduction in mean birth weight of 11%. In contrast, a study of similar CO exposure in rats, where 90 ppm produced COHb of 8.8%, found no reduction in birth weight (*36*). In the same study, rats breathing reduced oxygen (13%) did have lower birth weights, an effect thought to be caused by reduced food consumption.

In summary, although the categorization of fuel type used in this study and, by assumption, the levels of exposure were crude, it is likely to discriminate reasonably well. There is good evidence that the wood-fuel users (especially those with open fires) are exposed to hazardous levels of CO and other pollutants and that these levels are sufficient to cause IUGR. This assumes that it is CO exposure (or some other biomass smoke constituent) rather than nicotine that is the predominant mechanism by which cigarette smoking causes LBW. Exposure is in reality very complex and determined by the type and condition of the of wood (or other biofuel), the combustion device (open fire, stove of varying quality and state of repair), the time that women spend in the kitchen, and the contamination levels at or from adjacent homes of relatives and friends. Future studies of this and related health outcomes should, if resources permit, include direct measurement of exposure.

Studies of ambient air pollution and birthweight. We are not aware of any other human population studies of exposure to biofuel and birth weight, but several studies published recently have reported effects of ambient air pollutants on birth weight (*38–40*). Ritz et al. (*37*) studied over 125,000 births in Los Angeles and reported an adjusted odds ratio for LBW with third-trimester exposure to CO of > 5.5 ppm (3-month average) of 1.22 (1.03–1.44). In the study from China (*38*), the relationship between maternal exposure to ambient urban air pollution during pregnancy and birth weight was studied in a well-defined cohort between 1988 and 1991. After controlling for gestational age, residence, maternal age, year of birth, and sex of infant, the authors found a significant relationship between birth weight and maternal exposure to sulfur dioxide and total suspended particles (TSP) during the third trimester of pregnancy. The estimated reduction in birth weight was 7.3 g and 6.9 g for each 100 µg/m^3 increase in SO_2 and TSP, respectively. Data on CO levels were not reported. In an ecologic study of 45 districts in the Czech Republic, Bobak et al. (*39*) reported an adjusted odds ratio for LBW of 1.10 (1.01–1.20) for an increase of 50 µg/m^3 in SO_2. In this analysis, effects of TSP and NO_x were nonsignificant, and CO was not studied. Two further recent time-series studies from the Czech Republic have reported associations between IUGR and fine particulates (*40*) and polycyclic aromatic hydrocarbons (PAHs) (*41*), both of which are prominent components of wood smoke. In the former study, an adjusted odds ratio for IUGR for each 20 µg/m^3 increase in PM_{10} exposure in the first gestational month of 1.50 (95% CI, 1.15–1.96) was reported. In the latter study, exposure to PAHs in early pregnancy (first gestational month) produced an incremental adjusted odds ratio for IUGR of 1.22 (1.07–1.39) for each 10 ng increase in PAHs.

Magnitude of effect. This study has shown that after adjustment for relevant confounding variables, women using wood fuel had children with a mean birth weight some 63 g (0.4–126) less than that for women using cleaner fuels. Allowing for the classification error introduced by the relatively crude categorization of exposure, this effect could be expected to be greater among women consistently exposed to indoor biofuel pollution from poorly ventilated open fires.

Although errors introduced by variations in setting, measurement, type of exposure and other factors, as well as random error (as reflected in the wide confidence interval and marginal significance), make it unwise to overinterpret the actual magnitude of the effect on birth weight, there is nevertheless a degree of consistency between this study and those on active smoking, passive smoking, and urban air pollution. Active smoking is associated with effects of up to 200 g, ETS around 30–40 g. A study from South India reported a reduction of 63 g associated with ETS exposure among nonsmoking women, although it did not mention cook smoke or other sources of air pollution (*42*). The effect seen in the Chinese study would yield a reduction in birth weight of around 70 g for the 24-hr mean levels of 1,000 µg/m^3 reported for open fire homes in western Guatemala (the equivalent PM_{10} level would be a little lower than TSP in the case of indoor biofuel pollution) (*38*). This calculation, however, assumes a linear relationship somewhat beyond the data range for which the maximum TSP was 618 µg/m^3.

The consistency of this study with those of smoking, ETS, and ambient pollution suggests that this association with birth weight is indeed significant, as does the plausibility of a mechanism mediated through CO exposure and COHb (although this does not exclude other potential contributing mechanisms). The effect was independent of the confounding factors studied, albeit marginally, although the problem of dealing with confounding factors in observational studies on health effects of environmental risk factors such as indoor air pollution is recognized (*43*). Some evidence of a dose–response relationship was found, p = 0.08 (Table 2), although this was not apparent after adjustment. There should be no concern about the temporal relationship because we can safely assume that the exposure to wood smoke was present during the pregnancy among those reporting that they cooked with wood. It is possible that some women using wood during most of pregnancy changed later to a cleaner fuel and reported this as their main fuel during pregnancy, but this bias would tend to underestimate the true effect. There is also some supporting evidence from animal studies of exposure to tobacco smoke.

Attributable risk of indoor air pollution exposure. Overall, the evidence suggests that there may be an association between exposure to biofuel pollution and reduced birth weight, although this does need confirmation. Most households in developing countries still rely on biofuels for their daily cooking and heating needs; this rises to more than 80% in rural areas of some of the world's poorest countries (*23*). Women, particularly during their childbearing years, carry by far the greatest burden of cooking duties and exposure to indoor air pollution. This combination of high levels of CO and other pollutants, exposure of very large numbers of pregnant women over many hours each day, and high baseline levels of LBW implies that the global attributable risk for LBW-associated mortality and morbidity could be very substantial. Although the mean reduction in birth weight resulting from this exposure may not be as great as that seen with active smoking, the importance of shifting the distribution by even a small amount in a population with a high prevalence of LBW should perhaps not be underestimated (*44*).

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